

ASEAN Renewable Energy Integration Analysis

Flexibility benefits of cross-border power trade

October 2019



Executive summary

In support of Thailand's Association of Southeast Asian Nations (ASEAN) chairmanship, which aims to accelerate the development of the ASEAN Power Grid (APG), the IEA has undertaken the initial phase of a quantitative assessment of the impact of APG cross-border multilateral trade in accommodating the growing share of variable renewable energy (VRE), which consists of solar and wind generation.

The main objective of the study is to assess the value of regional power system integration in ASEAN in accommodating the growing share of VRE from economic, operational, environmental and policy-related aspects. The analysis explores the impact of multilateral power trading (MPT) and expanded cross-border interconnectors as well as the value of flexibility resources for the APG.

The assessment focuses on future scenarios for the region in 2035, analysing the impact of increased cross-border interconnection and multilateral trade on the accommodation of VRE. The results are based on projections of approximately 10% VRE generation in 2035, as described in the *5th ASEAN Energy Outlook*. They show that although enabling multilateral trade on all

existing and planned interconnectors as well as on subsequent expansion of the network reduces operational costs, in the absence of externality costs, CO₂ emissions increase owing to the greater operation and exports of coal-fired generation that multilateral trade allows. This emphasises the importance of taking measures to limit emissions, for example, by increasing the share of clean generation and applying clean air standards for fossil fuel generation.

Increasing the VRE share to align with projections from the IEA Sustainable Development Scenario (approximately 25% VRE generation in 2035) can unlock the full benefit of interconnectors and multilateral power trade. With the help of cross-border interconnectors, these higher shares of VRE can be accommodated without excessive curtailment, allowing reductions in both cost and emissions.

This highlights the operational, economic and policy-related impacts of VRE deployment and the value of cross-border interconnectors, which can support decision-making in system planning and operation in ASEAN.

Overview of the ASEAN Power Grid and renewable integration

The ASEAN Power Grid is an ambitious project to interconnect the power systems in the region.

Existing and planned ASEAN interconnection projects
(as of April 2019)



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The ten ASEAN member states (AMS) have a long-standing goal of integrating their respective power systems, articulated in the proposed ASEAN Power Grid (APG). The concept of the APG was formally adopted by ASEAN in 1997 as part of the ASEAN Vision 2020. This support was reaffirmed in 2012 with the signing of the “Memorandum of Understanding on the ASEAN Power Grid” (ASEAN, 2012).

The APG is a proposed set of cross-border transmission lines that, when completed, will fully interconnect the ten ASEAN member states (AMS). The APG is divided into three sub-regions: North, South and East. Most progress to date has occurred in the North region of Cambodia, Lao People’s Democratic Republic (Lao PDR), Thailand and Viet Nam.

The APG is seen by the AMS as a tool to stimulate regional economic growth and development. Increased regional integration allows the AMS to meet rising demand more efficiently and securely.

Cross-border interconnections facilitate multilateral trade and the integration of variable renewable energy (VRE) in ASEAN

Southeast Asia is increasingly influential on the global energy stage. Its energy demand has grown by 60% in the past 15 years (IEA, 2017a). The potential for renewable energy (RE), which is abundant, is distributed across the region.

RE plays an important role for sustainable development by enhancing energy security through fuel diversification, reducing the dependency on imported fuels, and contributing to the mitigation of climate change. The cost of renewable energy, particularly solar PV and onshore wind, has decreased significantly in recent years. It promises to be cost-competitive with conventional generation technologies (ACE, 2019).

The ASEAN Plan of Action for Energy Cooperation (APAEC) 2016-2025 set a RE target of 23% by 2025 in total primary energy supply (ACE, 2015). Cross-border interconnection, a key enabler for multilateral power trade, facilitates the integration of higher shares of RE, particularly wind and solar PV, in the ASEAN power system. It has a number of potential benefits.

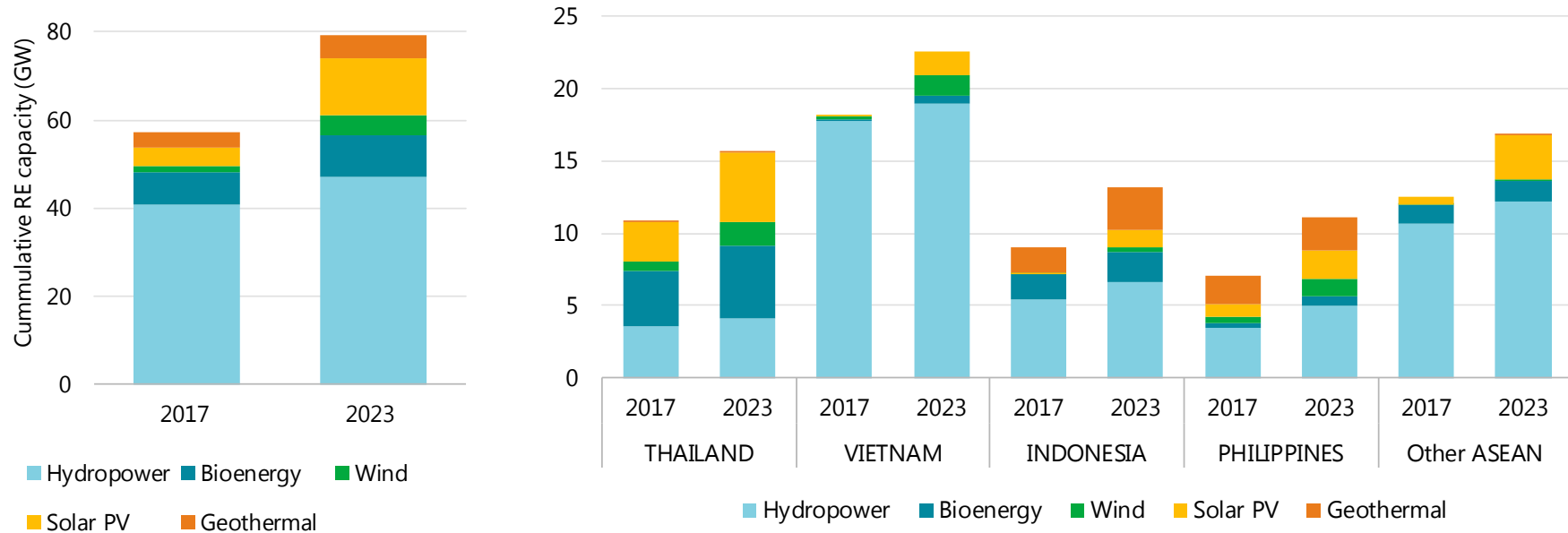
- **Security of supply:** Interconnected networks enhance

regional security of supply by enabling effective utilisation and resource sharing across geographical locations for common regional benefit. Reserve capacity to ensure reliable power supply can also be shared.

- **Economic benefits:** Interconnectors can achieve measurable savings in peak capacity needs. They can also provide economic benefits by allowing the cost-effective generating units within the interconnected area to be dispatched, and by enabling power trade between the systems.
- **Integration of VRE:** Interconnectors facilitate the integration of VRE into the power system in a cost-effective and reliable manner (IEA, 2016). Interconnectors enable flexibility resources to be shared across different countries. A larger geographical area will also smooth the variability, and reduce the uncertainty, of VRE generation.

ASEAN renewable capacity to grow by over a third by 2023

ASEAN cumulative renewable capacity, 2017 and 2023

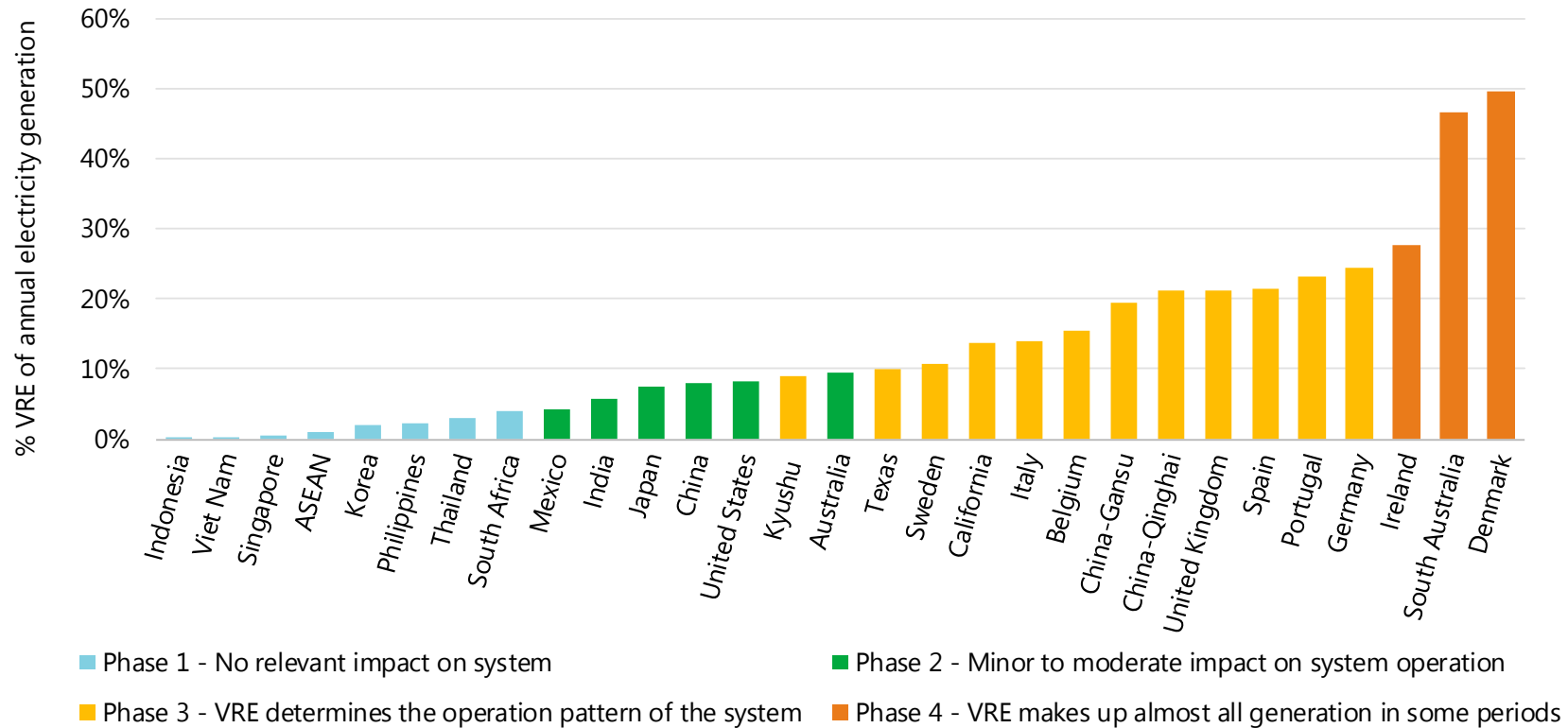


Source: Adapted from IEA (2018a), *Renewables 2018: Analysis and Forecasts to 2023*.

The share of RE is forecast to account for around 20% of electricity generation in ASEAN. The growth in wind and solar PV raises system integration challenges. Cross-border interconnection is a key flexibility resource that facilitates renewable energy integration.

System integration can be classified into different phases

VRE shares in total electricity generation by region in 2018



Source: IEA (2019a), *Status of Power System Transformation 2019*.

Previous IEA analysis has identified different phases of system integration, according to the impact of VRE at the system level (IEA, 2017b). A variety of system-specific factors influence how much an increase in VRE will affect the overall flexibility requirements of the system. Currently, many countries and regions are still in Phases 1 and 2, but they are expected to be moving to higher phases in the coming years.

Interconnections are a main source of system flexibility that facilitate the growing share of variable renewable energy

With the rapid growth of wind and solar PV generation, or variable renewable energy (VRE), securing the provision of system flexibility has become increasingly important for policy makers.

With increasing VRE penetration, power system flexibility becomes a more prominent issue that requires policy makers' attention.

Electricity grids (including cross-border interconnectors) are one of four key flexibility resources. Other resources include power plants (both conventional and VRE); energy storage; and demand-side response (IEA, 2019a).

The ASEAN Power Grid (APG) is a key flexibility resource that can allow the integration of higher shares of VRE. So far, the development of the APG has been mainly bilateral. Most AMS have interconnections of some kind, with trade arrangements mostly limited to unidirectional power trades under power purchase agreements (PPAs) or bidirectional trading of electricity without financial compensation.

Recently, however, the AMS have begun a reinvigorated push to fully develop the APG, including the establishment of multilateral power trading. This includes a pilot multilateral trading project between Lao PDR, Malaysia, Thailand, and Singapore, and an IEA-led study on pathways to develop multilateral power trade in the region (IEA, 2019b).

Approach to assess the value of cross-border interconnection and renewables in ASEAN

Modelling approach

Scenarios and key assumptions

Quantitative assessment of the value of cross-border interconnection and multilateral trade for the integration of variable renewables

This analysis builds upon the detailed study, entitled *Thailand Renewable Grid Integration Assessment*, conducted by the IEA in 2018 (IEA, 2018b).

Four selected transmission zones* are modelled with their total cross-border interconnection capacities in the initial phase of the analysis.

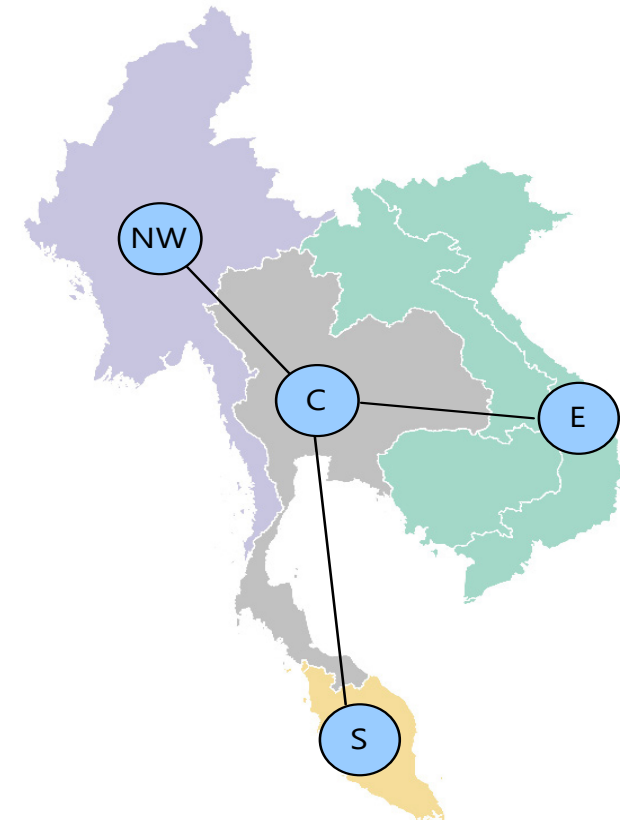
C: Central (Thailand); **E:** East (Cambodia, Lao PDR and Viet Nam); **NW:** North-west (Myanmar) and **S:** South (Malaysia and Singapore).

While these locations possess a number of existing cross-border interconnectors, they are mostly limited to bilateral trading with PPAs. The benefit of multilateral trade is estimated by comparing scenarios with different trade arrangements and shares of VRE.

Hourly production cost modelling based on unit commitment economic dispatch has been developed to assess projections of ASEAN's power system in 2035.

In the model, hourly variation of load and VRE in different regions, as well as technical constraints on the power system, are represented.

Four selected transmission zones in ASEAN



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* Brunei, Indonesia, Philippines and non-Peninsular Malaysia are not taken into consideration due to limited resources and availability of data.

A number of scenarios to assess the value of multilateral power trading and expanding cross-border interconnectors

Scenarios and key criteria for the analysis

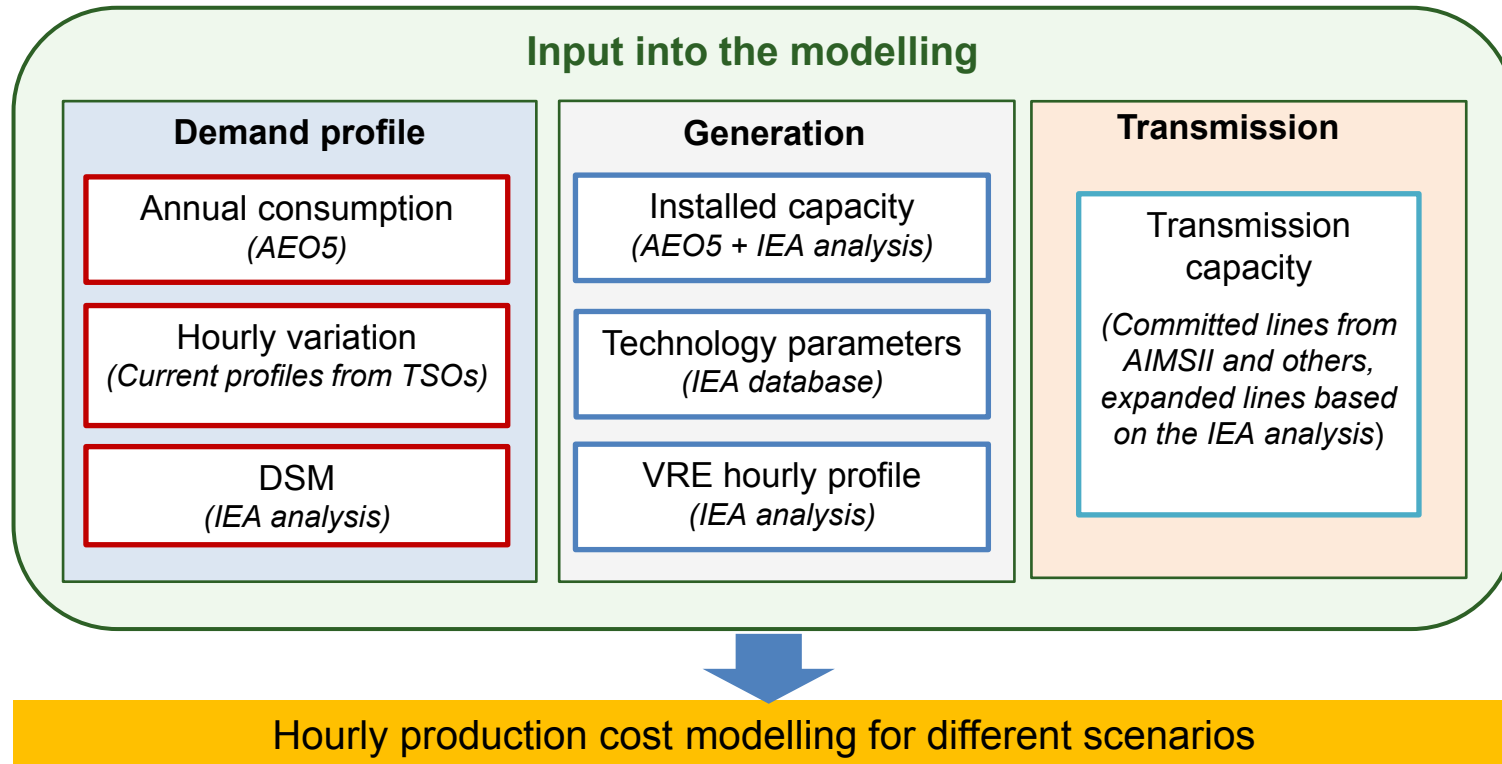
| No. | Scenario | Key criteria | | |
|-----|-------------------------------------|----------------------------------|--------------------------------|--------------|
| | | Cross-border trading arrangement | Cross-border transmission grid | Share of VRE |
| 1 | Bilateral trade (Bilat_trade) | Bilateral with PPA | Existing | ~10% |
| 2 | Multilateral trade (Multi_trade) | Multilateral trade | | ~10% |
| 3 | Bilateral trade with high VRE | Bilateral with PPA | | ~25% |
| 4 | Multilateral trade with high VRE | Multilateral trade | | ~25% |
| 5 | Expanded transmission (Expanded_Tx) | Multilateral trade | Expanded | ~10% |
| 6 | Expanded Tx with high VRE | Multilateral trade | | ~25% |

Six main scenarios are examined. In each scenario, there are three key criteria:

- **Cross-border trading arrangement:** Bilateral, which constrains the utilisation of interconnectors; or multilateral trade, which optimises the usage of interconnectors.
- **Cross-border transmission grid:** Considers the existing cross-border infrastructure or expanded transmission lines.
- **Share of VRE:** Two different scenarios of VRE annual share are examined: low VRE (~10%) and high VRE (~25%). These are ambitious targets compared to today's situation, but they are also in line with the current levels of VRE in a number of countries in Asia, Europe and the United States. The high share of VRE is based on the IEA Sustainable Development Scenario (SDS) (IEA, 2018c).

Overview of the production-cost modelling approach

Quantitative modelling framework

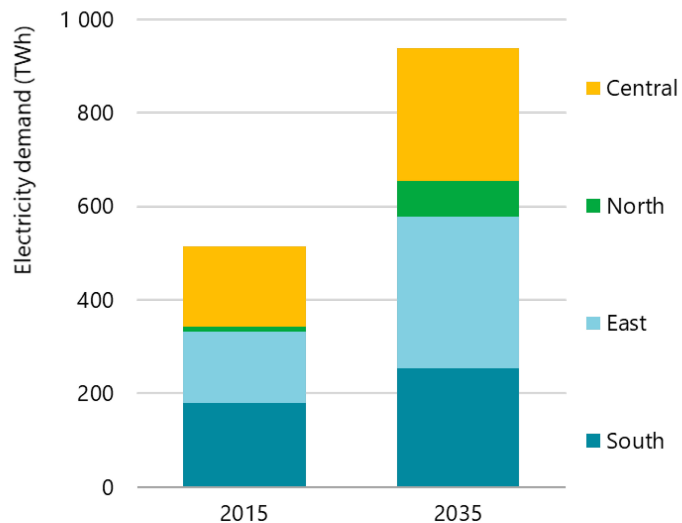


There are three key input data that require detailed evaluation: estimating the future demand profile, generation parameters, and transmission capacity. In the model, hourly variation of load and VRE in different regions as well as technical constraints in the power system are all represented.

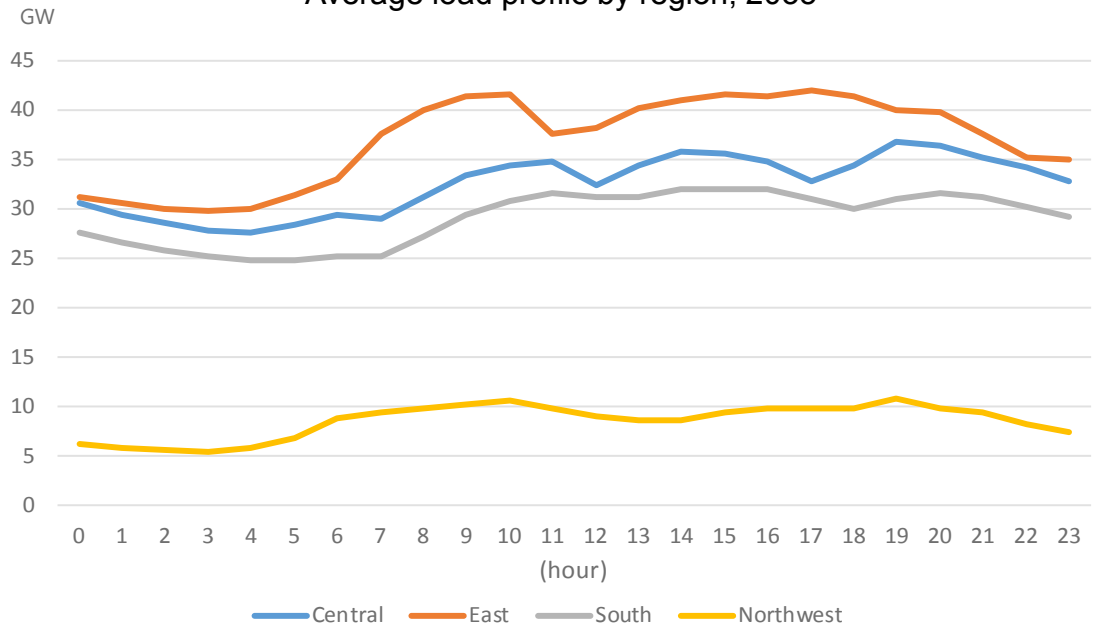
The study refers to the 5th *ASEAN Energy Outlook* (AEO5) by the ASEAN Centre for Energy (ACE, 2016) and IEA analysis for input into the modelling.

Estimating future electricity demand in 2035

Projected electricity demand by zones, 2035



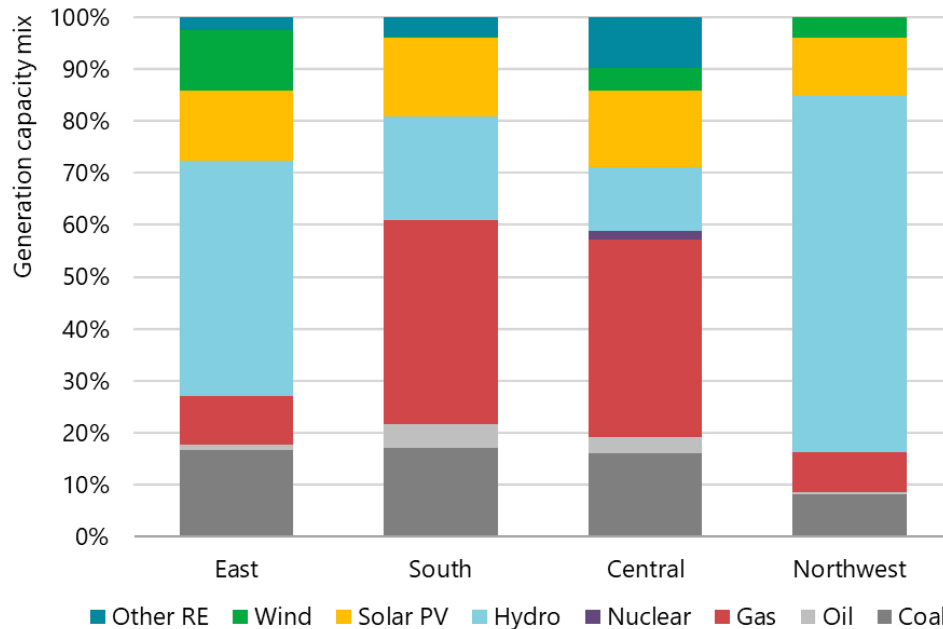
Average load profile by region, 2035



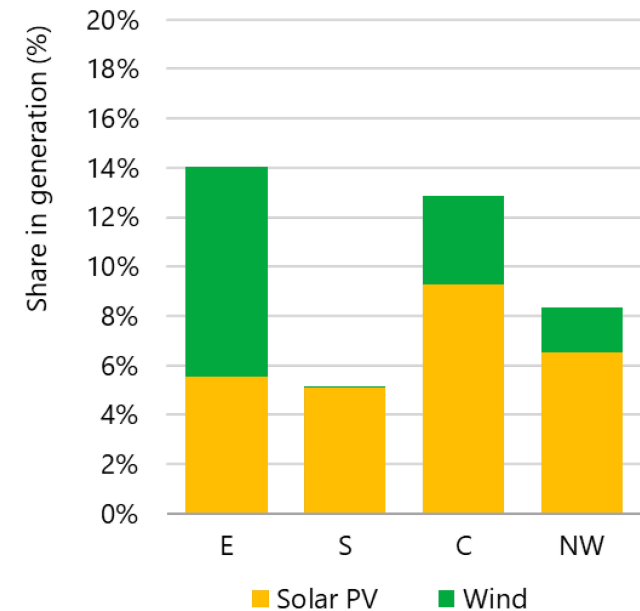
Electricity demand in 2035 is based on the ASEAN Progressive Scenario (APS) in AEO5, with additional consideration for the cooling sector. The demand is projected to increase by more than 80% compared to 2015, based on a top-down approach driven by economic and population growth considering efficiency improvement policies. Cooling load, which is explicitly modelled, is derived from *The Future of Cooling: Opportunities for Energy-Efficient Air Conditioning* (IEA, 2018d).

Electricity generation capacity in 2035

Generation mix by technology (%), 2035



Share of wind and solar PV generation for each region, 2035



The study assumes the power generation capacity projected in the AEO5 under the ASEAN Progressive Scenario (APS) with the capacity ranging from 25 GW to 120 GW in different regions (ACE, 2017).

Under the APS, the share of solar PV and wind generation is around 10%, which is considered as the low VRE scenario in the analysis.

Key findings

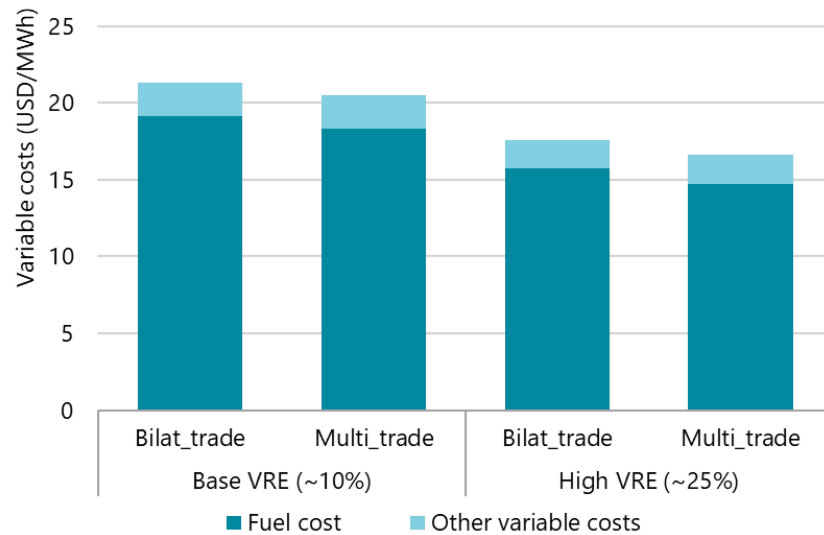
Potential value of multilateral power trade in ASEAN

Benefits of expanding cross-border interconnectors

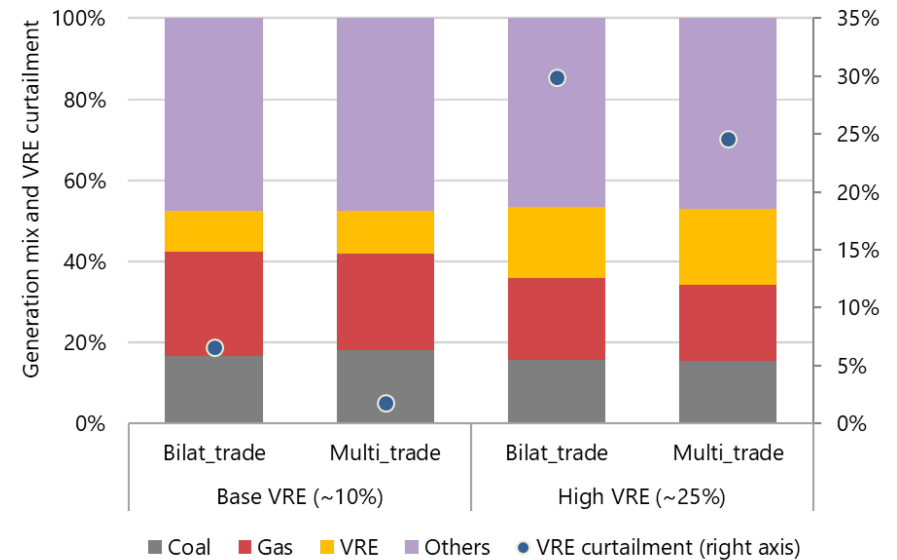
The impact and value of altering capacity mix in different regions

Multilateral power trade in ASEAN can facilitate a higher share of VRE and lead to lower operational costs for the system

Annual operational costs

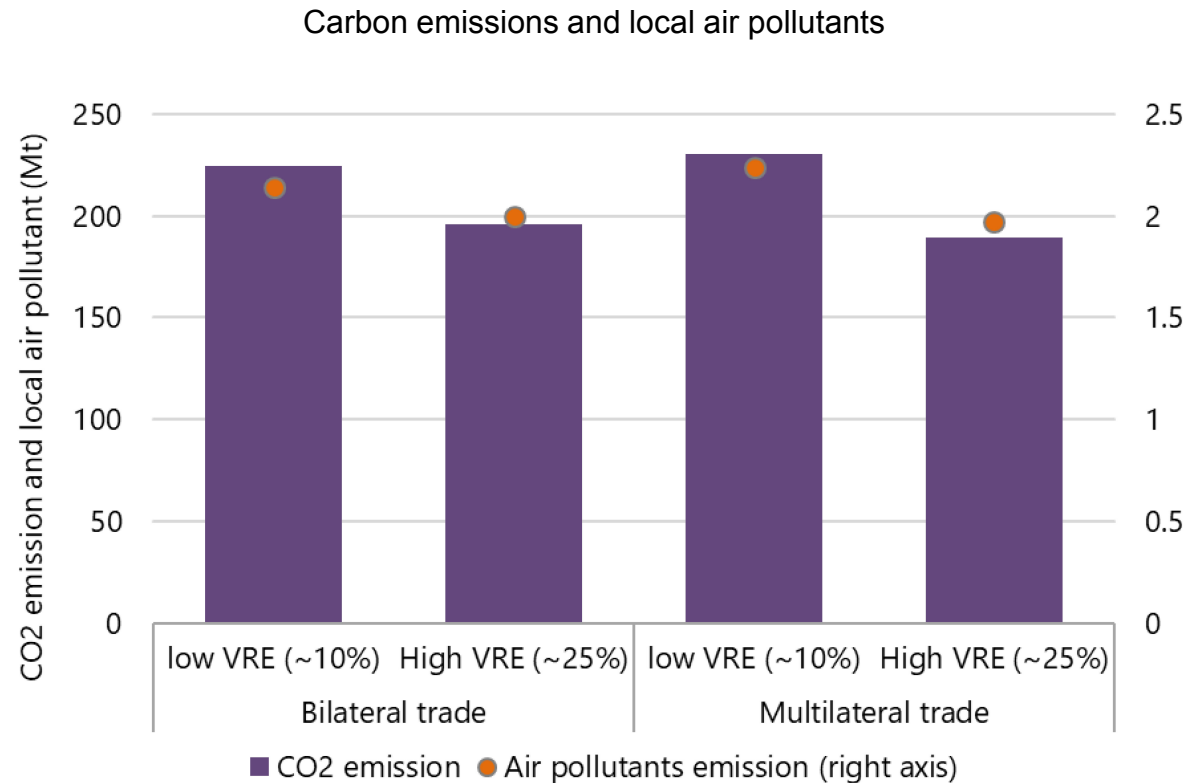


Generation mix and VRE curtailment



Allowing multilateral trade leads to more cost-effective utilisation of the cross-border interconnectors while also reducing curtailment of VRE generation.

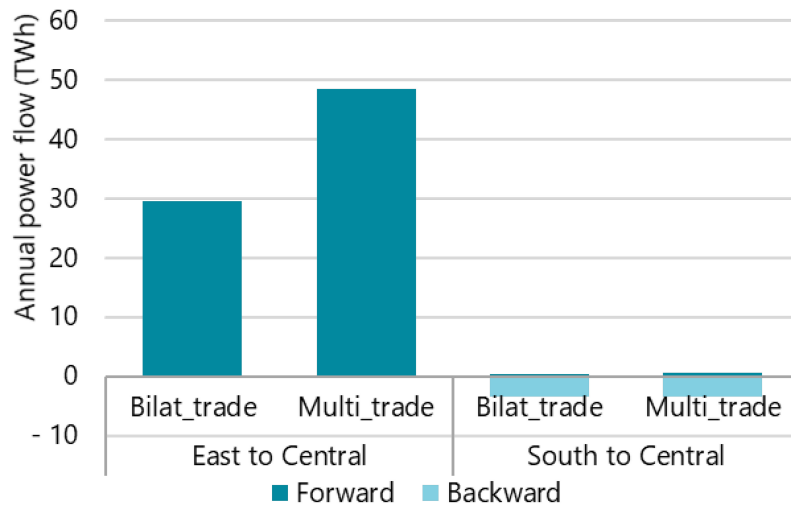
Multilateral trade combined with high VRE penetration brings environmental benefits



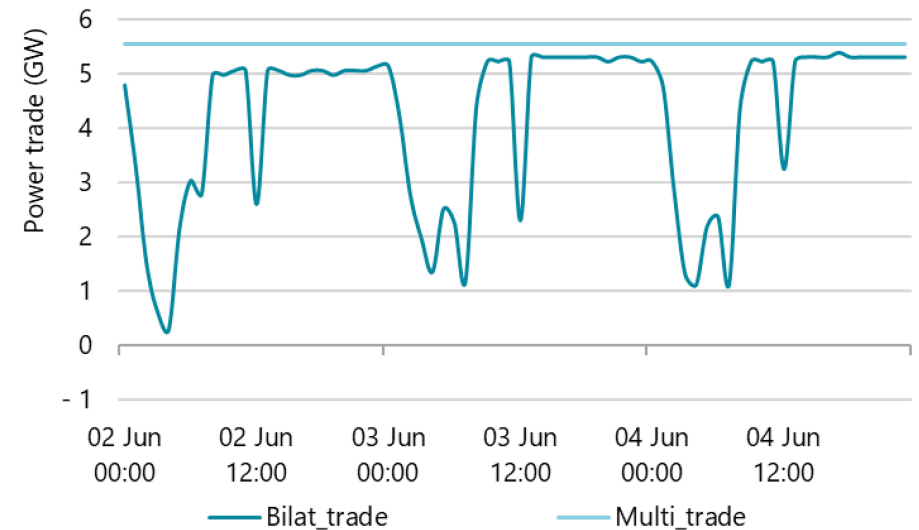
While increased interconnection usage can be a pathway to facilitate VRE integration, it may also increase coal-fired generation if externalities are not considered. At high VRE penetrations, increased interconnection leads to overall emission reductions.

Multilateral power trade arrangements allow increased utilisation of cross-border interconnectors

Cross-border power flow in the case with low VRE (~10%)



Power flow from East to Central during peak demand periods



With bilateral trade, power flows from East to Central are based on generation from power purchase agreement (PPA) contracted hydropower in the East exporting to the Central region. With multilateral trading, the utilisation rate of these interconnectors increases from around 60% to 90%.

Multilateral power trade in ASEAN has potential economic, operational and environmental benefits

Optimising cross-border flows through multilateral trade – based on the existing cross-border infrastructure – can reduce annual operational costs of the ASEAN power sector by USD 1 billion. This corresponds to a supply cost reduction of around USD 1 per MWh. Multilateral trade enables the integration of higher VRE.

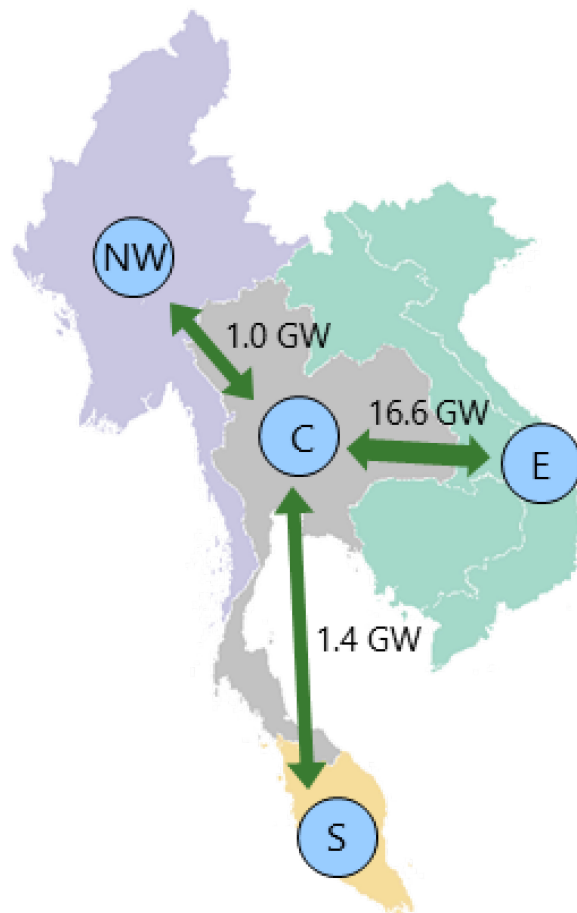
Multilateral trade can result in increased coal-fired generation due to their low operating costs since externalities, such as carbon price, are not considered. With a low VRE share, this can lead to an increase in carbon emissions and air pollutants. This emphasises the importance of measures to limit emissions, such as increasing the share of clean generation and applying clean air standards for fossil-fuel generation. With a high share of VRE, multilateral trade helps to reduce environmental impacts since VRE can replace coal-fired generation. The level of VRE curtailment can still rise with higher VRE shares; however, this can be addressed with increased interconnection capacity (see the next section).

Multilateral trade leads to more cost-effective utilisation of the existing cross-border interconnectors. It allows for greater electricity flows from regions with lower generation costs, such as hydro and VRE generation in the Eastern

region to the Central region. With bilateral trading, the use of the East to Central interconnectors is mostly for exporting hydro generation from the Eastern region, which varies over time. Under multilateral trading, the Eastern region consistently exports to the Central region.

Expansion of cross-border interconnectors in ASEAN to assess its potential benefits

Capacity of the interconnectors



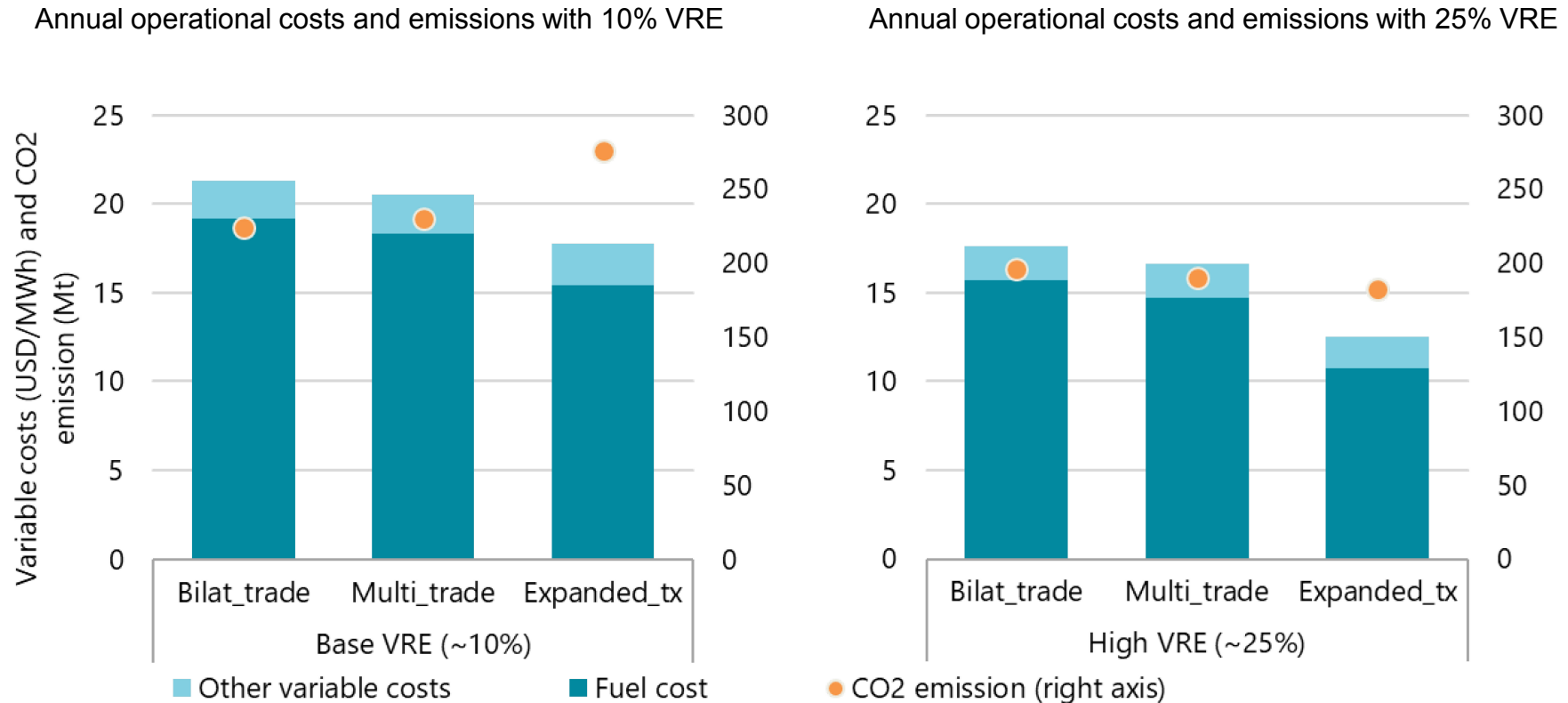
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Transmission expansion candidates that were considered are based on either existing lines or are candidates as included in the ASEAN Interconnection Master Plan Study II (AIMSII) (APGCC, 2015). The lines for the scenarios with expanded cross-border interconnectors were then selected through a cost-optimisation process based on minimising both operational and capital expenditure, assuming annualised build costs over an economic life of 40 years.

As a result, 13 GW of cross-border interconnectors are added to the existing capacity, which is around 6 GW. The estimated investment cost of the expansion is around USD 18 billion¹, most of which is between the Eastern and Central regions, enabling trade of low-cost generation, particularly hydro and VRE, from the Eastern region.

¹ Calculated based on assumed investment cost, discount rate and expected lifetime of different types of transmission lines.

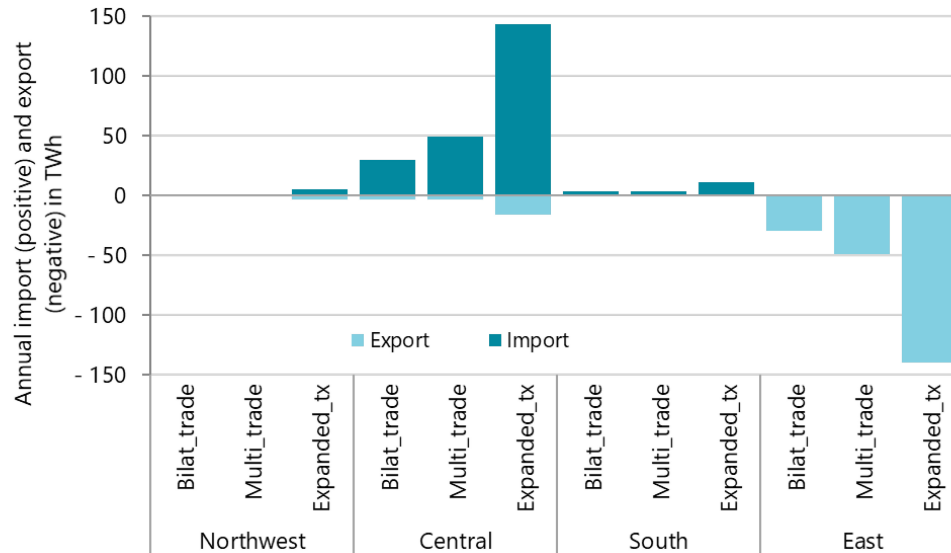
Expanding cross-border interconnectors yields further economic and environmental benefits, when combined with a high share of VRE



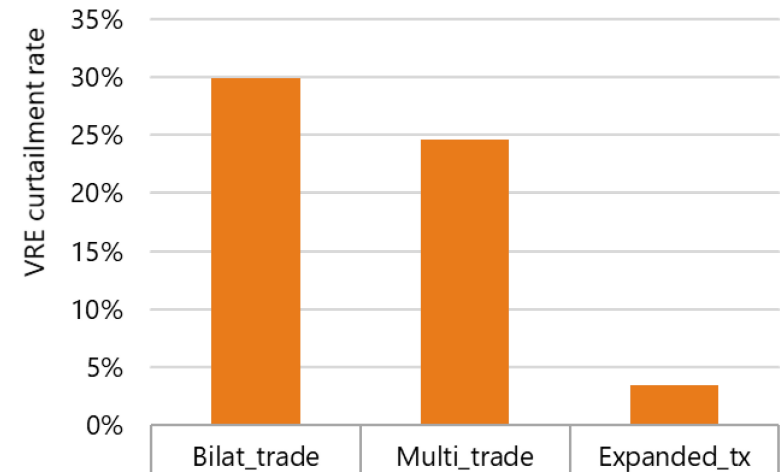
The full benefit of interconnectors is unlocked when accommodating a higher share of VRE because it can bring both economic and environmental benefits even without externality costs.

Expanded interconnectors enable higher VRE penetration and enhance the sharing of resources across regions through power exchange

Annual power import/export by region with high VRE (~25%)

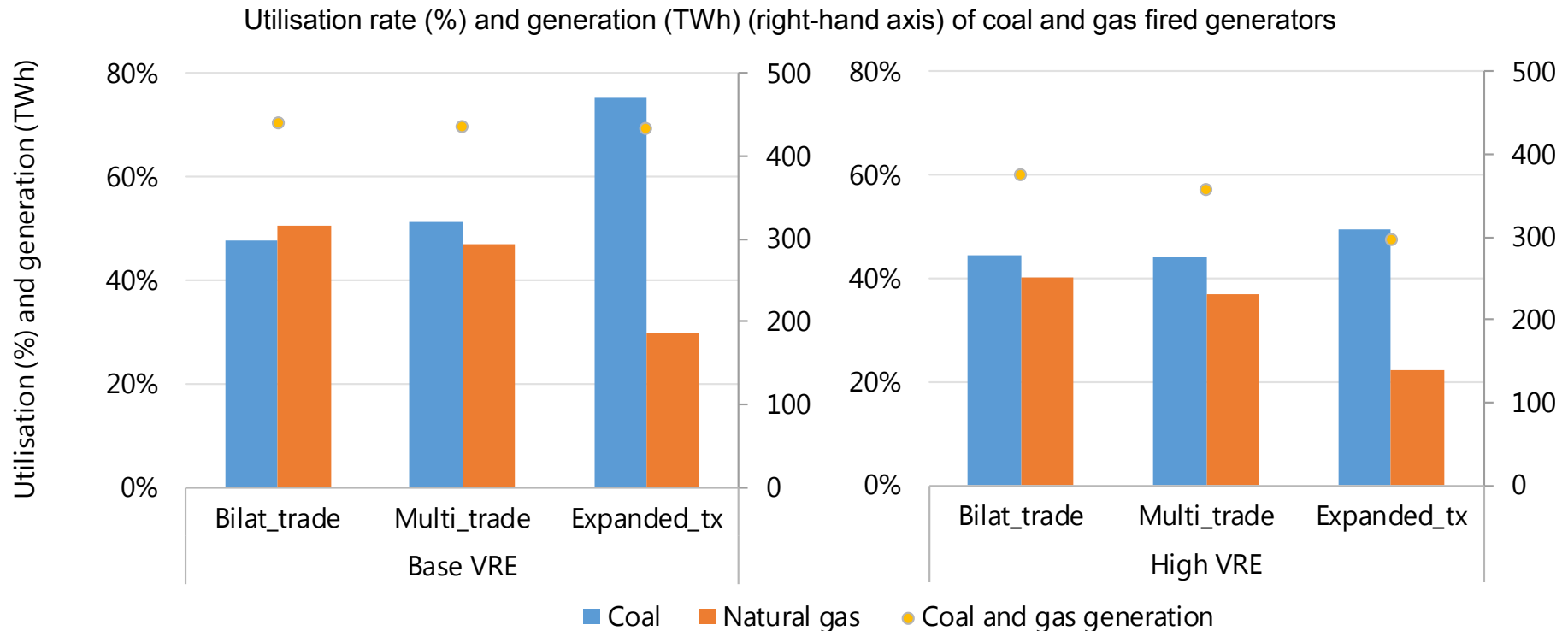


VRE curtailment for high VRE (~25%)



Expanded transmission enables greater trade between regions while leading to economically more reasonable levels of curtailment.

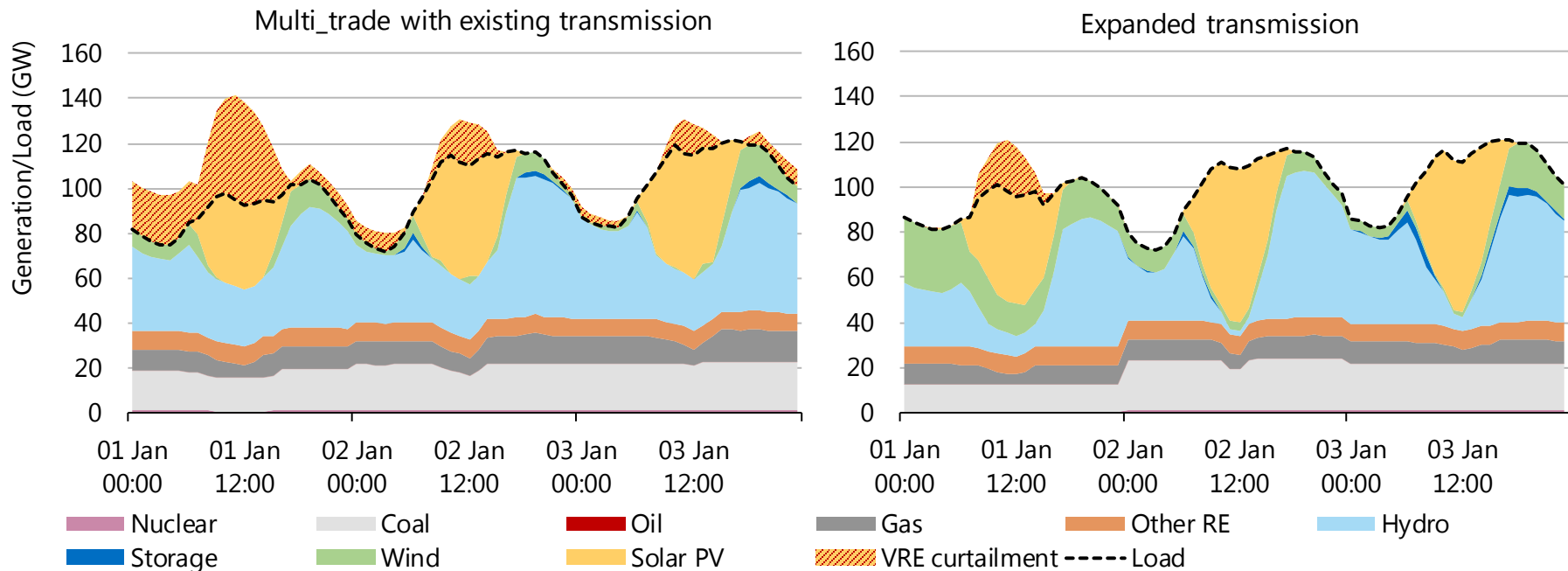
Expanded interconnectors will change generation patterns of thermal generators



Expanding interconnectors will impact the utilisation of conventional generators. Coal-fired generators are dispatched more often due to their relatively low operational costs. Utilisation of gas-fired generators reduces in general; however, the impact is very different by region. Re-optimisation of the power development plan in each region assuming expanded interconnection will be important to attract adequate power sector investment and to ensure minimum societal cost overall.

Additional cross-border interconnections provide operational flexibility

Generation pattern during the period of minimum demand with high VRE (~25%)



Expanded transmission allows for absorption of more VRE, with hydropower helping to balance the variation in supply and demand.

Expanding cross-border interconnectors in ASEAN brings economic, operational and environmental benefits

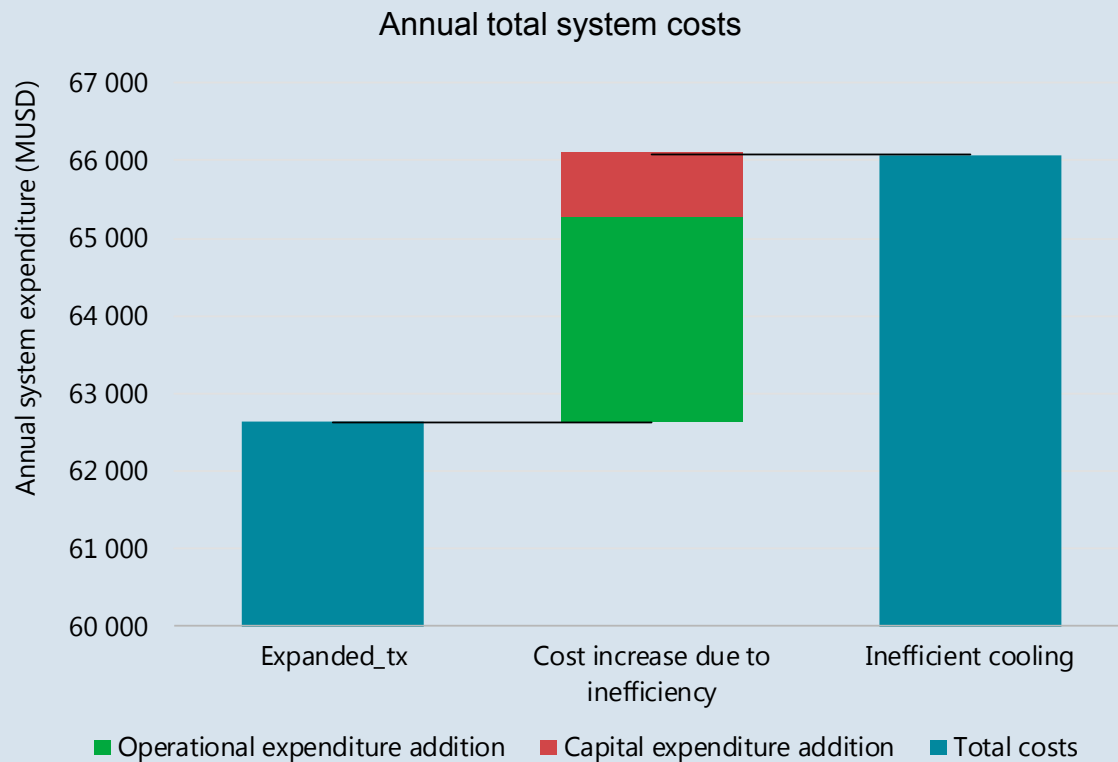
Expanding the cross-border interconnection infrastructure in ASEAN provides further economic benefits and can accommodate greater shares of VRE. The operational costs can be reduced by USD 4-5 billion annually. Together with a push towards low-carbon generation, cross-border interconnectors can also bring strong environmental benefits, even without considering environmental and social costs.

With additional interconnectors, the operational cost savings outweighs the additional annuitised investment cost of USD 1-2 billion, bringing net economic benefit. Total system costs (including fixed costs) of the high VRE cases are comparable to those with low VRE. With the increasing share of VRE, the expansion of interconnectors can be the most cost-optimal solution when externality is considered. Also, the expansion of interconnectors reduces capacity requirement for peak generation as a result of lower peak demand, which brings further economic benefit.

From the operational aspect, expanded transmission aids system operation, particularly during a period of high

system stress, such as minimum system demand, by allowing greater VRE penetration and avoiding significant curtailment. The flexible role of hydro generation, including pumped storage hydro (PSH), helps in balancing the variability of VRE generation and demand. The increased use of PSH also illustrates the potential for expanded interconnection to enable the contribution from flexibility resources such as storage.

BOX 1 • Efficiency improvement in electricity demand should be considered at the same time



Cooling demand is the fastest-growing demand in ASEAN. The APS scenario assumes reasonable energy efficiency measures. The value of energy efficiency can be evaluated in comparison with an inefficient cooling case to demonstrate the key role of energy efficiency to provide cost-effective energy services.

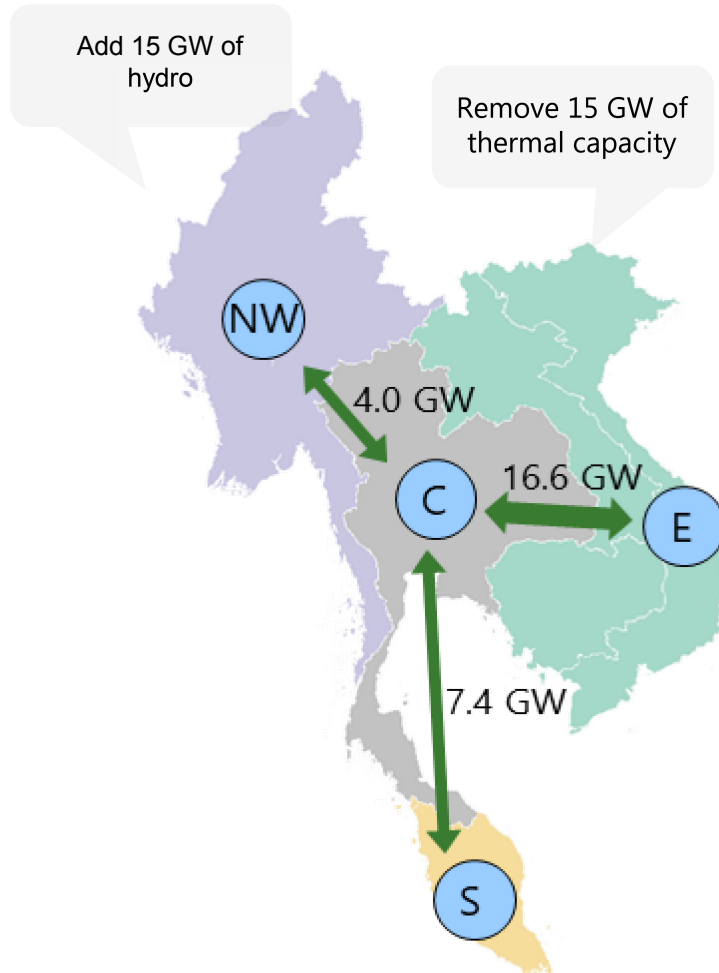
For example, applying efficient cooling appliances* not only reduces electricity consumption, but it also allows the power system to burn fewer fossil fuels during peak periods, resulting in a significant reduction in both cost and emissions. With a lower peak demand, total system cost is further reduced because less generation capacity is required.

Note: Annual total system costs is a sum of annual operational costs and annuitised capital costs. Capital expenditure savings are calculated based on the generation capacity, which is not utilised in the simulations.

* In this analysis, for simplicity, annual total system costs to supply electricity to meet increased demand (assuming inefficient cooling appliances) are compared with the costs to meet the demands assumed in the main scenarios. Each case assumes multilateral trade with expanded interconnectors under high VRE share (~25%).

Additional scenarios with alternative capacity mix in different regions

Capacity of the interconnectors in the additional scenarios

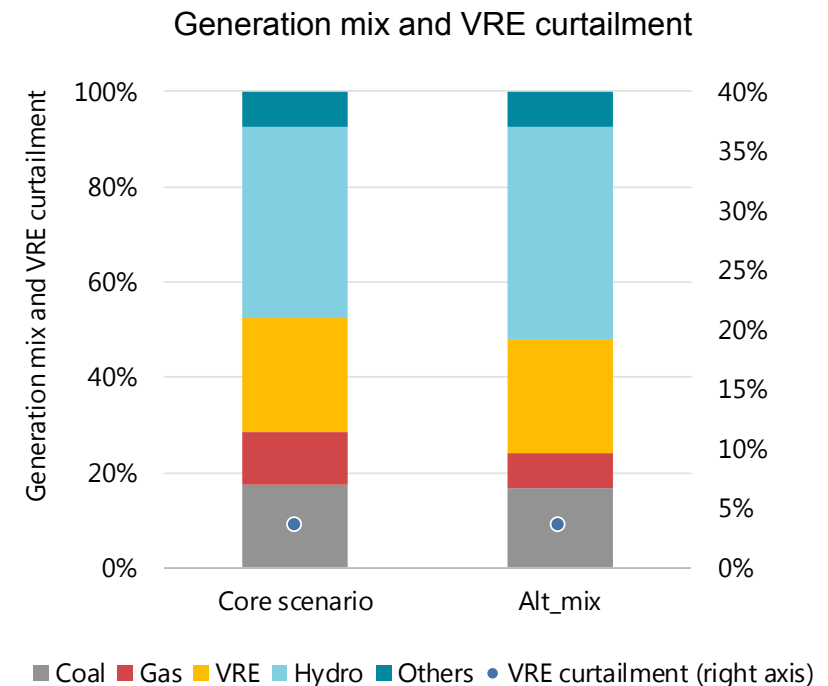
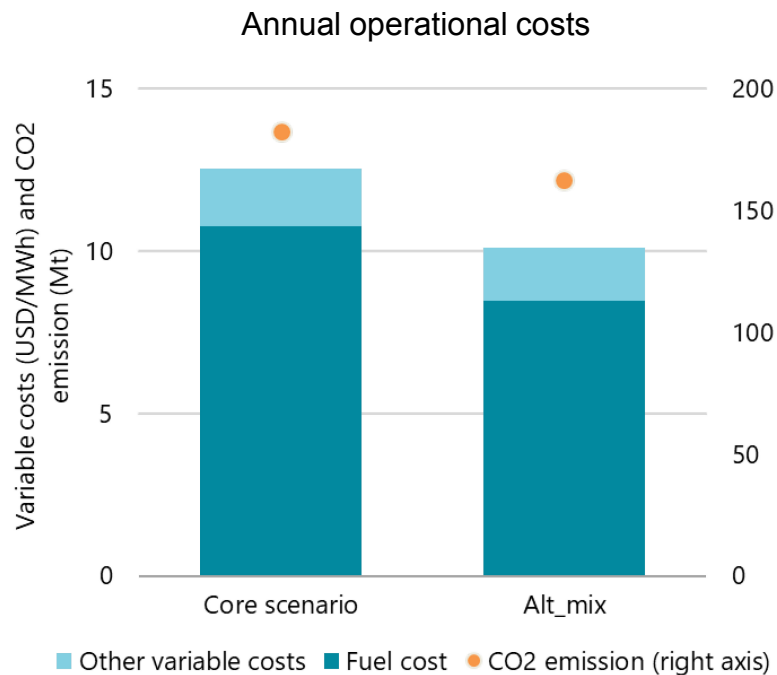


Additional scenarios with a different generation capacity mix were also examined. Considering the large untapped potential for hydro capacity in the North-western region in the core scenarios, as presented in the previous section, 15 GW of hydro was added to the North-west. In order to keep the same overall generation capacity in the combined regions, 15 GW of under-utilised coal and gas were also removed from the Eastern region.

Additional cross-border interconnectors are again selected through a cost-optimisation process based on the new generation capacity and demand in each region. In this case, around 4 GW and 7 GW of cross-border interconnectors are added between the Central and North-western and Central and Southern regions, respectively, with an estimated investment cost of USD 32 billion.

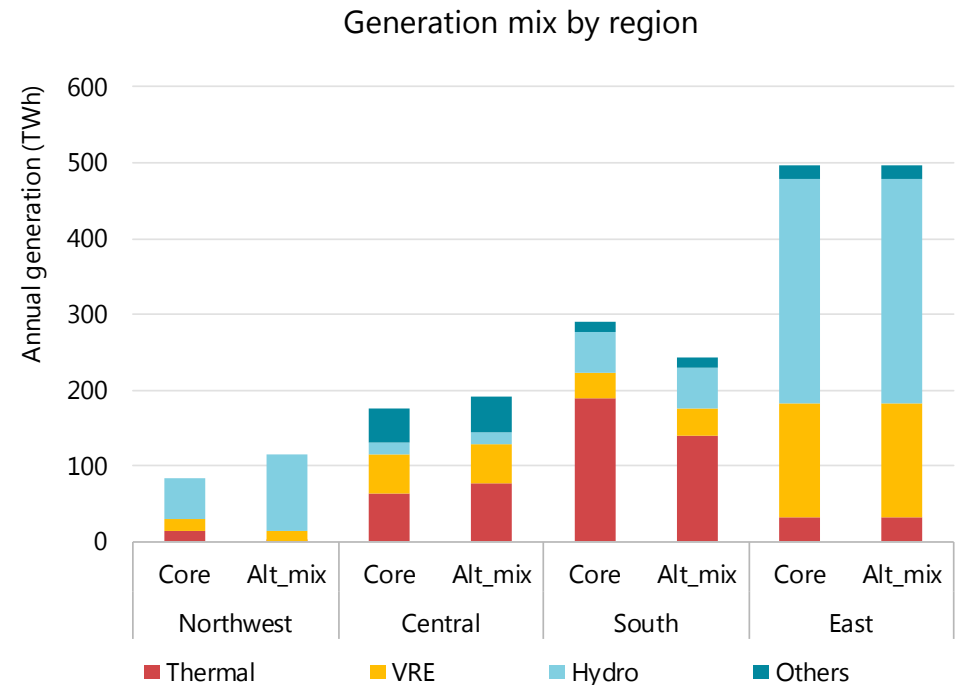
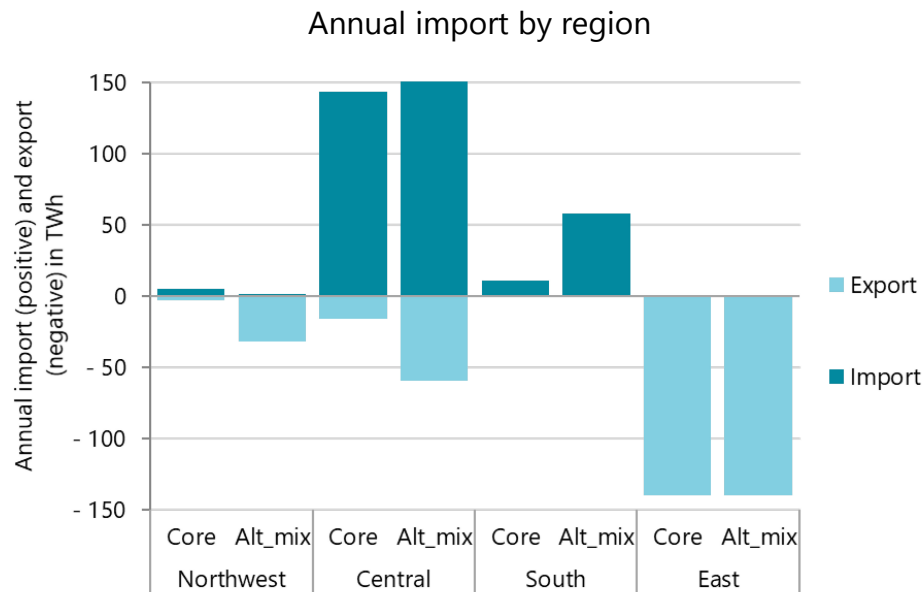
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Interconnectors will bring further benefit under a co-ordinated power system planning approach



Compared to the scenario assuming AEO5 capacity mix with a higher VRE share (“Core”), expanding interconnectors under the alternative capacity mix (“Alt_mix”) enables further operational cost and emission reduction. In particular, the North-western region has abundant hydro potential that is more than sufficient to meet domestic demand, and increased interconnection would provide economic and environmental benefits for ASEAN.

The impact of the alternative capacity mix on generation trade



Exports from the North-west increase due to the larger hydro availability, while, at the same time, power exchange between the Central and Southern regions increases notably. As a result, a significant part of thermal generation (predominantly gas-fired) in the South is replaced by imports, resulting in cheaper electricity prices in the region.

Key findings and recommendations

Cross-border interconnectors with multilateral power trade in ASEAN promote effective asset utilisation and resource sharing with regional benefits. A number of common benefits can be achieved covering economic, operational and environmental aspects, which are relevant for all stakeholders.

Cross-border interconnectors enhance the flexibility of the ASEAN power sector to accommodate an increasing share of renewables, particularly solar and wind. This allows a higher share of VRE to be integrated into the ASEAN power system in a cost-effective and reliable manner. The operational cost savings outweigh the additional investment cost for interconnectors in both low and high VRE cases, bringing net economic benefit. With high VRE penetrations, increased interconnection leads to overall emission reductions.

Alternative generation capacity mixes in different regions can also lead to further reduction in operational costs and emissions. The abundant hydro potential in the North-western region (Myanmar) is sufficient not only for meeting domestic demand, but also for exporting to other countries with expanded cross-border interconnectors. This leads to overall economic and environmental benefits for ASEAN.

The potential of cross-border interconnectors to connect low-cost and low-carbon resources flourishes when a harmonised approach is taken to planning the future power system of this region, with an aim to ensuring an affordable, reliable and sustainable electricity supply. It is important to build upon existing efforts and to enhance the trading arrangements and physical grid infrastructure in ASEAN.

Annex

Acknowledgments

Existing generation capacity

Estimated cooling load

Total system costs

References

Acknowledgments

The ASEAN Renewable Energy Integration study was conducted in support of Thailand's ASEAN Chairmanship in 2019, which aims to accelerate the development of the ASEAN Power Grid (APG) in accommodating the growing share of renewable energy.

The IEA would like to thank Thailand's Ministry of Energy and Electricity Generating Authority of Thailand (EGAT) for providing financial support for this study and for organising a consultation workshop and facilitating meetings with ASEAN stakeholders.

This report was prepared by the System Integration of Renewables (SIR) Unit of the Directorate of Energy Markets and Security (EMS). The study was led and co-ordinated by Peerapat Vithayasrichareon. The main authors were Craig Hart, Zoe Hungerford, and Yugo Tanaka. The study benefited from support provided by Kieran Clarke, Randi Kristiansen and Matthew Wittenstein.

The IEA team would like to thank the ASEAN member states (AMS) for their engagement and support throughout the project. The authors are grateful for the comments and feedbacks received from a number of ASEAN member state institutions, particularly the ASEAN

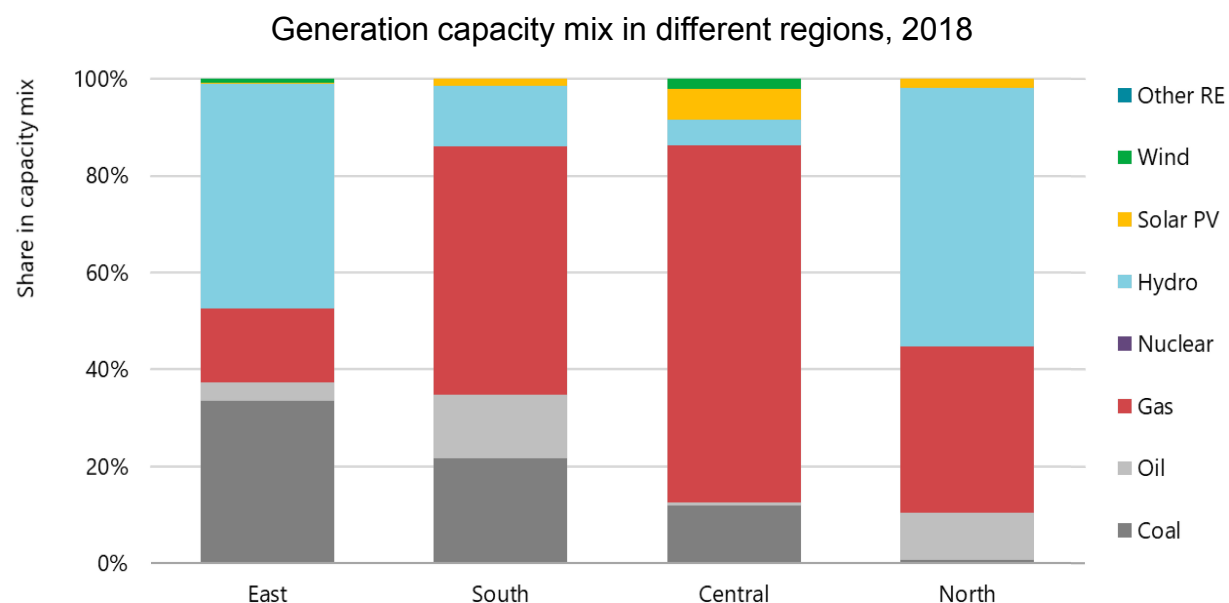
Secretariat, the Heads of ASEAN Power Utilities and Authorities (HAPUA), the ASEAN Power Grid Consultative Committee (APGCC) and the ASEAN Renewable Sub-sector Network (RE-SSN).

The IEA team would also like to thank the ASEAN Centre for Energy (ACE) for providing necessary data and information for the analysis. We also thank David Gernaat from Utrecht University for providing hydro resource data.

Valuable comments and advice were provided by IEA senior management and other IEA colleagues, in particular: Keisuke Sadamori, Director of EMS; Paolo Frankl, Head of Renewable Energy Division; Laura Cozzi, Head of Energy Modelling Office, Energy Demand Outlook Division; Tim Gould, Head of Energy Supply and Investment Outlook Division; Edwin Haesen, Head of SIR Unit; Chiara Delmastro, John Dulac, Maxine Jordan, Luis Lopez, Wataru Matsumura, Claudia Pavarini, Melanie Slade and Brent Wanner.

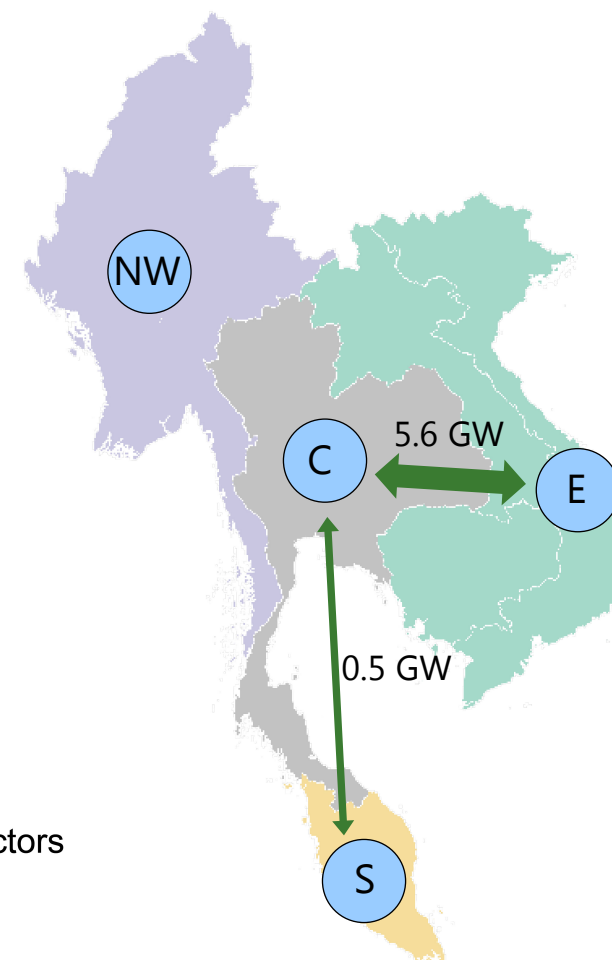
The authors would like to thank the IEA Communications and Digital Offices (CDO) for producing this report, including Astrid Dumond, Christopher Gully, Jethro Mullen, Robert Stone and Therese Walsh.

Existing generation capacity and interconnectors



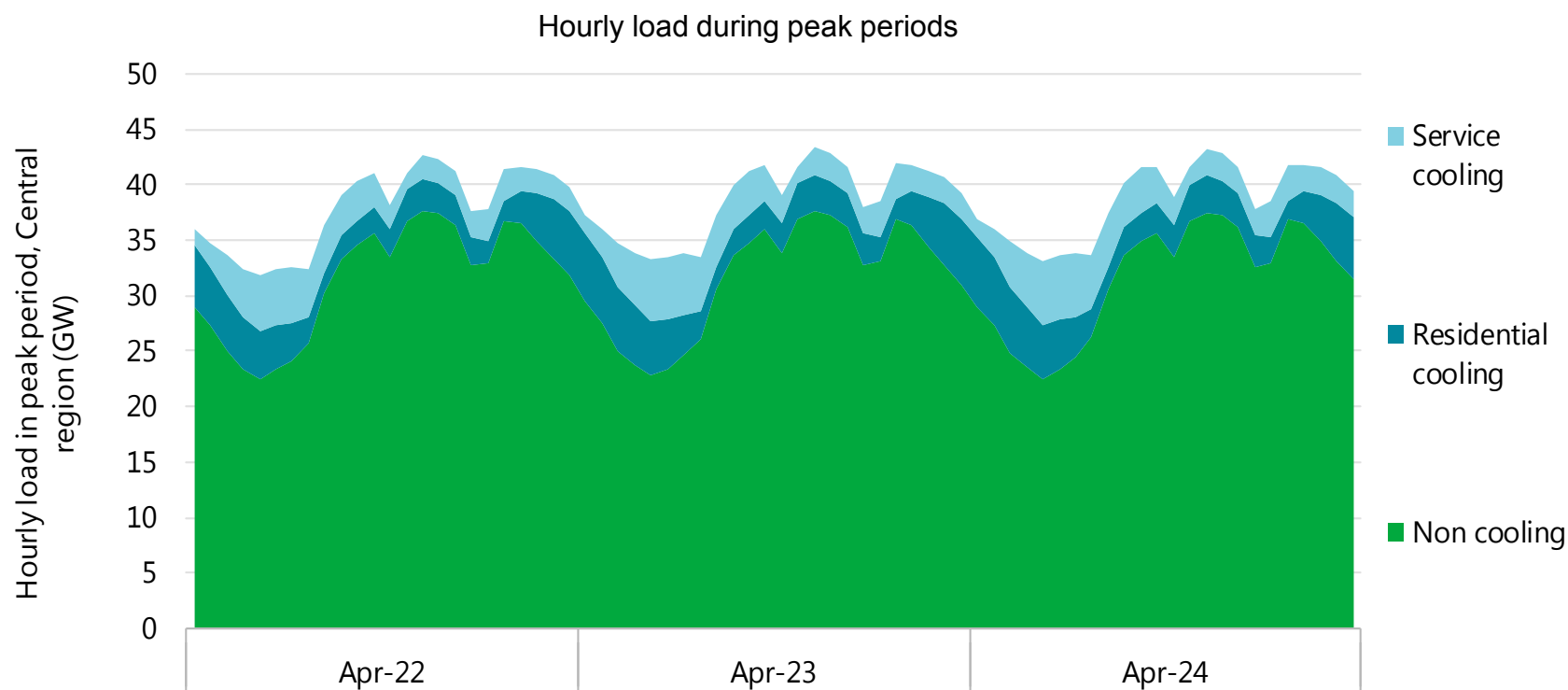
- Existing and committed interconnectors are treated as “existing”
- Modelled on a line-by-line basis
- In the scenarios which assume bilateral trade, the power flows of interconnectors that have been built for power import/export based on PPAs are constrained

Capacity of the existing cross-border interconnectors



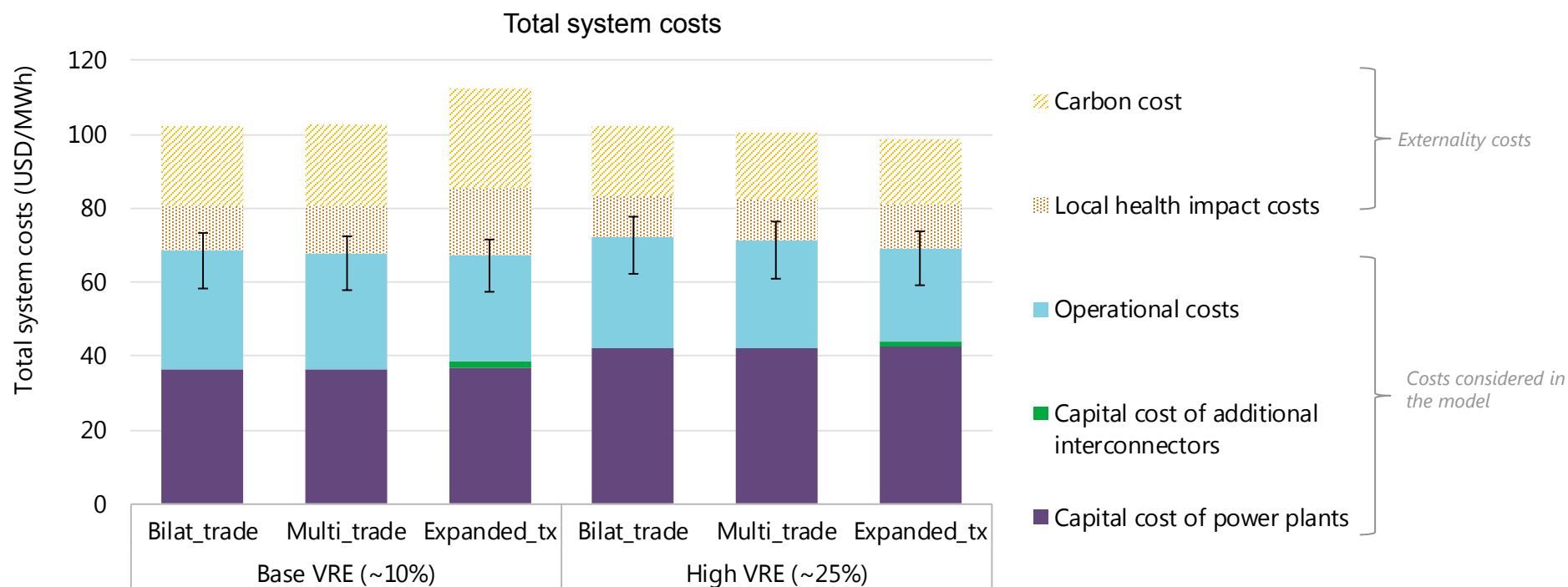
This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Demand response of estimated cooling load



Cooling load of each region is estimated bottom-up based on available data, so that the impact of demand side management can be measured

Total system cost with and without externality



Without externality costs, the operational cost saving outweighs the additional investment cost for interconnectors, bringing net economic benefit. The expansion of interconnectors while increasing the share of VRE can give substantially lower total system costs when externality is considered.

*Total system costs estimated based on our own assumptions; capital cost is annuitized assuming assets are built green field on the study year; existing transmission and distribution infrastructure is not included; uncertainty range reflects a range of fuel price and technology cost assumptions reported in other studies; carbon cost assumes carbon price of 100USD/ton-CO₂; air pollution costs are calculated based on PM, NO_x and SO_x emission, using estimated costs of health impact in EC CAFÉ programme (2005).

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Design in France by IEA – October 2019